08:46:56 OCA PAD AMENDMENT - PROJECT HEADER INFORMATION 12/06/95

Active

Project #: E-25-X66 Cost share #: Rev #: 8
Center # : 10/24-6-R7707-0A0 Center shr #: OCA file #:
Work type : RES
Contract#: DDM-9396052 Mod #: AMENDMENT 004 Document : GRANT
Prime #: Contract entity: GTRC

Subprojects ? : Y CFDA: 47.041
Main project #: PE #: N/A

Project unit: MECH ENGR Unit code: 02.010.126
Project director(s):
MISTREE F MECH ENGR (404)894-8412
ALLEN J K MECH ENGR (404)-

Sponsor/division names: NATL SCIENCE FOUNDATION / GENERAL
Sponsor/division codes: 107 / 000

Award period: 921201 to 960831 (performance) 961130 (reports)

Sponsor amount	New this change	Total to date
Contract value	3,017 00	174,027.00
Funded	3,017.00	174,027.00
Cost sharing amount		0.00

Does subcontracting plan apply ?: N

Title: DESIGNING AT THE FUNCTIONAL LEVEL OF ABSTRACTION

PROJECT ADMINISTRATION DATA

OCA contact: Jacquelyn L. Bendall 894-4820

Sponsor technical contact

F. STAN SETTLES
(703)306-1328

NATIONAL SCIENCE FOUNDATION
4201 WILSON BLVD.
ARLINGTON, VA 22230

Sponsor issuing office

MARIA VALERIO
(703)306-1218

NATIONAL SCIENCE FOUNDATION
4201 WILSON BLVD.
ARLINGTON, VA 22230

Security class (U,C,S,TS) : U ONR resident rep. is ACO (Y/N): N
Defense priority rating : N/A NSF supplemental sheet
Equipment title vests with: Sponsor GIT X

Administrative comments -
AMENDMENT NO. 4 ADDS $3,017 TO PROJECT.

U

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

NOTICE OF PROJECT CLOSEOUT

Closeout Notice Date 11/05/96

Project No. E-25-X66 Center No. 10/24-6-R7707-0A0

Project Director MISTREE F School/Lab MECH ENGR

Sponsor NATL SCIENCE FOUNDATION/GENERAL

Contract/Grant No. DDM-9396052 Contract Entity GTRC

Prime Contract No.

Title DESIGNING AT THE FUNCTIONAL LEVEL OF ABSTRACTION

Effective Completion Date 960831 (Performance) 961130 (Reports)

Closeout Actions Required:	Y/N	Date Submitted
Final Invoice or Copy of Final Invoice	N	
Final Report of Inventions and/or Subcontracts	N	
Government Property Inventory & Related Certificate	N	
Classified Material Certificate	N	
Release and Assignment	N	
Other	N	

Comments
LETTER OF CREDIT APPLIES. 98A SATISFIES PATENT REPORT.

Subproject Under Main Project No.

Continues Project No.

Distribution Required:

Project Director	Y
Administrative Network Representative	Y
GTRI Accounting/Grants and Contracts	Y
Procurement/Supply Services	Y
Research Property Managment	Y
Research Security Services	N
Reports Coordinator (OCA)	Y
GTRC	Y
Project File	Y
Other	N
	N

E25-X66

ANNUAL REPORT
(12/92- 4/93)

DDM 93-96502

DESIGNING AT THE FUNCTION LEVEL OF ABSTRACTION

FARROKH MISTREE AND JANET K. ALLEN
SYSTEMS REALIZATION LABORATORY
THE GEORGE W. WOODRUFF SCHOOL OF MECHANICAL ENGINEERING
GEORGIA INSTITUE OF TECHNOLOGY
ATLANTA, GEORGIA 30332-0405

Summary: In the early stages of project initiation, it is especially important to be able to represent at a high level of abstraction the functional requirements of a system being designed. This would make it possible for a design team to arrange and rearrange the essential functional components rapidly. It is well-known that design for manufacture tools are implementable and useful once the design of a component is known. But what if we want to address the issue of design for manufacture when only the function is known? At present, this remains an open question. The development of the means to include manufacturing considerations in design when only the functional requirements are known is the focus of this proposal. Two students, Pat Koch and Jesse Peplinski are working on this project.

Status:

1 *Modeling Function of a Product using Living System Theory Icons:* We have modeled the function of three systems, namely, a lawn mower, an aircraft evacuation system and a thermal energy system. A paper on this is expected to be completed by the end of the Spring Quarter. The lawn mower example was initially developed as part of an SBIR grant (Muster, Allen and Mistree) and details for the aircraft evacuation system were provided by Dr. Sudhir Hublikar of the BF Goodrich Company, Aircraft Evacuations Systems Division in Phoenix, Arizona and Dr. Jon Shupe of the BF Goodrich Company R&D Center in Brecksville, Ohio. We are particularly pleased with the set of examples - since two of them have been developed with significant industry input.

2 *Representation of Product Information in Electronic Catalogs:* This issue was investigated during the Winter Quarter. Assuming that we have large catalogs we need a two step process. One that we can use to identify the most likely to succeed alternatives and the other to identify the configuration of the system. This investigation continues.

3 *Modeling Interfaces between Subsystems:* We are looking into this by using the Transmission Entities of Miller's Living Systems Theory. We expect to define a generic interface in terms of matter, energy and information to link two dissimilar available assets. We have not cracked this problem yet.

4 *Undergraduate Students* We have applied for two Research Experiences for Undergraduates Supplements to NSF in December 1992.

5 *Remaining Tasks:*
- Design for assembly at the function level of assembly.
- Partitioning a system from different perspectives.
- Designing for continuous improvement.
- Design of the computer system.
- Identifying fundamentals (à la John Dixon's definition) for designing at the function level of abstraction.

5 *Commentary:* The grant we received was about half of what we requested leaving money for supporting one graduate student instead of the three that we had requested. We are happy to report that we have two students working on this project; one supported by funds from this grant and one who until recently was supported by the George W. Woodruff School of Mechanical Engineering (he has just received an NSF Graduate Research Award). We still have had to alter our original proposal: Instead of modeling manufacturing processes using Miller's icons we have decided to look at the assembly of systems using available assets. This reduces the complexity of the problem and ties into our other grant, namely, the Design of Hierarchical and Non-Hierarchical Systems using Decision Support Problems.

The Aircraft Evacuation System example has been used to introduce the seven TQM Management and Planning tools (in the context of Pahl & Beitz' approach to establishing function structures) to students in our first course in design in Spring 1993: ME3110 - Creative Decisions and Design. We intend to clean this work up and publish it as a paper.

Design using available assets, in our opinion, is important particularly in a period of reduced defense expenditures. Mistree has been invited to prepare a briefing on this subject for ARPA in June 1993.

Disassembly for recycling and reuse is becoming increasingly important. Allen and Bras have submitted a proposal to NSF titled: Environmentally Conscious Design based on Living Systems Theory.

Publications in which this grant is acknowledged

1. F. Mistree, B.A. Bras, W.F. Smith and J.K. Allen, "Modeling Design Processes: A Conceptual, Decision-Based Approach" in *Mechanical Design Theory and Methodology,* (M. Waldron, Ed.), New York: Springer-Verlag, (in press).
2. F. Mistree, J.K. Allen and F. Attia, "Designing at the Function Level of Abstraction", *Proceedings NSF Grantees Conference on Design and Manufacturing Systems Research, Charlotte,* NC, January 1993, pp. 621-627.
3. F. Mistree, J.K. Allen and F. Attia, "Designing at the Function Level of Abstraction", *Behavioral Science,* Vol. 38, 124-138. This paper was invited by the Editor, J.G. Miller and has been edited by him.

E-25-X66
N/A

APPENDIX D

ANNUAL NSF GRANT PROGRESS REPORT

NSF Program: DMII

NSF Award Number: DDM 93-96052

PI Name: Farrokh Mistree
Janet K. Allen

Period Covered By This Report: 4-93 - 4-94

PI Institution: Georgia Tech

Date: 5-1-94

PI Address: The G. W. Woodruff School of Mechanical Engineering
Georgia Tech
Atlanta, GA 30332-0405

☒ **Check if Continued Funding is Requested**

Please include the following information:

1. Brief summary of progress to date and work to be performed during the succeeding period;
2. Statement of funds estimated to remain unobligated –if more than 20%– at the end of the period for which NSF currently is providing support (not required for participants in the Federal Demonstration Project);
3. Proposed budget for the ensuing year in the NSF format, **only** if the original award letter did not indicate specific incremental amounts or if adjustments to a planned increment exceeding the greater of 10% or $10,000 are being requested;
4. Current information about other research support of senior personnel, if changed from the previous submission;
5. Any other significant information pertinent to the type of project supported by NSF or as specified by the terms and conditions of the grant;
6. A statement describing any contribution of the project to the area of education and human-resource development, if changed from any previous submission; and
7. Updated information on animal care and use, Institutional Biohazard Committee and Human Subject Certification, if changed substantially from those originally proposed and approved.

I certify that to the best of my knowledge (1) the statements herein (excluding scientific hypotheses and scientific opinions) are true and complete, and (2) the text and graphics in this report as well as any accompanying publications or other documents, unless otherwise indicated, are the original work of the signatories or individuals working under their supervision. I understand that the willful provision of false information or concealing a material fact in this report or any other communication submitted to NSF is a criminal offense (U.S. Code, Title 18, Section 1001.)

P.I. Signatu

NSF Form 1328 (1/94)

ANNUAL NSF GRANT PROGRESS REPORT FOR DDM 93-96502

DESIGN AT THE FUNCTIONAL LEVEL OF ABSTRACTION

1. Progress to Date

Summary of Work Proposed In the early stages of project initiation, it is especially important to be able to represent at a high level of abstraction the functional requirements of a system being designed. This would make it possible for a design team to arrange and rearrange the essential functional components rapidly. It is well-known that design for manufacture tools are implementable and useful once the design of a component is known. But what if we want to address the issue of design for manufacture when only the function is known? At present, this remains an open question. The development of the means to include manufacturing considerations in design when only the functional requirements are known is the focus of this proposal. Two graduate students, Pat Koch and Jesse Peplinski are working on this project.

Status:

1. *Modeling Function of a Product using Living System Theory Icons:* We have modeled the function of three systems, namely, a lawn mower, an aircraft evacuation system and a thermal energy system. The lawn mower example was initially developed as part of an SBIR grant (Muster, Allen and Mistree) and details for the aircraft evacuation system were provided by Dr. Sudhir Hublikar of the BF Goodrich Company, Aircraft Evacuations Systems Division in Phoenix, Arizona and Dr. Jon Shupe of the BF Goodrich Company R&D Center in Brecksville, Ohio. We are particularly pleased with the set of examples - since two of them have been developed with significant industry input.

   Design Using Available Assets: In the early stages of the product realization process, if the functional requirements of the system to be designed can be partitioned and represented, concepts can be quickly explored which represent specific concepts. Thus designers are able to explore different system configurations at a high level of abstraction. If components or component assemblies which perform certain functions exist, a designer can easily determine the feasibility of realizing at least some of the product specific functions by using available assets. To date, we have focused on the use of existing components to realize a new design, although, potentially, machines, processes, tools, facilities, plants, capital, employees, etc. are also available assets. As an example of our methods of design at the functional level of abstraction we have demonstrated the design of an aircraft evacuation system for the next generation of aircraft, Koch et al., 1993. We believe that this work provides the foundation for an unusual, but theoretically correct approach to continuous quality improvement, CQI.

   The benefits of designing using available assets, include the following:

   - Reduced time to market: eliminate or greatly reduce the component design time and manufacturing time.
   - Reduced cost: design labor and manufacturing costs are reduced.
   - Increased quality: existing products, components and component assemblies possess built in quality.

   We believe that in these days of military down-sizing, and emphasis on sustainable development, design using available assets is essential. Further information about design using available assets is presented in Koch, et al., 1993.

Design for Disassembly/Reuse: Design at the functional level of abstraction also is an important tool for design for disassembly/design for recycling and reuse. Preliminary studies indicate that, similarly to the way manufacturing considerations are introduced, it is also feasible to introduce constraints from other segments of the life cycle. We have considered also introducing information from the "disposal" phase of the life cycle and using this information to create environmentally friendly products.

After developing satisfactory system representations for single-instants on the design time line, we plan to link them in series to show product evolution. Then, for any instant on the time line, system design or redesign is feasible. We are in the process of developing our thoughts in this area.

2. *Remaining Tasks:*
   - Design for assembly at the function level of assembly.
   - Designing for continuous improvement.
   - Design of the computer system (in progress).
   - Identifying fundamentals (à la John Dixon's definition) for designing at the function level of abstraction.

3. *Commentary:* The grant we received was about half of what we requested leaving money for supporting one graduate student instead of the three that we had requested. We have had to alter our original proposal: Instead of modeling manufacturing processes using Miller's icons we have decided to look at the assembly of systems using available assets. This reduces the complexity of the problem and ties into our other grant, namely, the Design of Hierarchical and Non-Hierarchical Systems using Decision Support Problems, DDM 93-96503.

Publications in Which This Grant Has Been Acknowledged

Journal Articles

1. P. Koch, J. Peplinski, J.K. Allen, and F. Mistree, (1993) "Designing Using Available Assets: Identifying a Feasible System Configuration", *Behavioral Science,* in press.
2. F. Mistree, J.K. Allen and F. Attia, "Designing at the Function Level of Abstraction", *Behavioral Science,* Vol. 38, 124-138. This paper was invited by the Editor, J.G. Miller and has been edited by him.

Chapter in Book

3. F. Mistree, B.A. Bras, W.F. Smith and J.K. Allen, "Modeling Design Processes: A Conceptual, Decision-Based Approach" in *Mechanical Design Theory and Methodology,* (M. Waldron, Ed.), New York: Springer-Verlag, (in press).

Conferences

4. F. Mistree and J.K. Allen, "Designing at the Function Level of Abstraction", *Proceedings NSF Grantees Conference on Design and Manufacturing Systems Research,* Cambridge, MA, January 1994, pp. 71-72.
5. F. Mistree, J.K. Allen and F. Attia, "Designing at the Function Level of Abstraction", *Proceedings NSF Grantees Conference on Design and Manufacturing Systems Research, Charlotte,* NC, January 1993.
6. P.N. Koch, J.K. Allen and F. Mistree, "Modeling Concurrent Design, A Decision-Based Conceptual Exposition" (Abstract) to be presented at the 3rd Industiral Engineering Research Conference, Atlanta, Georgia, May 18, 1994.

Thesis

7. A. Rothe, Decision Support Problems in the Pahl/Beityz Design Process, M.S. Thesis, G.W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, March 1994.
8. P.N. Koch, Design Using Available Assets at the Functional Level of Abstraction, M.S. Thesis, G.W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, Georgia, expected, June 1994.

2. We do not anticipate more than 20% of the funds we have received from this grant will remain un-obligated in December which will be the beginning of the award year.

3. **Proposed budget -** As approved.

4. **Current information about research support -** See attached.

5. **Other information** - None.

6. **Updated information about contributions of this project to the area of education and human-resource development.**

Undergraduate Students: We have received two Research Experiences for Undergraduates Supplements this grant and one award for our companion grant DDM-93-96503. We are proud of the accomplishments of our undergraduates. The NSF-REU program has allowed us to establish an active undergraduate research program in our laboratory. During the last year, ten undergraduates have been affiliated with our group in one way or another (B. Ackroyd, K. Alexander, D. Bier, E. Christal, R. Dailey, D. Nelson, D. Tibbets, Z. Siddique, K. Watley and T. Yu). Two of these will graduate in June and have been admitted to The G. W. Woodruff School of Mechanical Engineering at Georgia Tech for graduate studies (K. Alexander and Z. Siddique), and one has taken a job in industry (E. Christal) and the remainder are still undergraduates. In addition, K. Alexander has been accpeted for the Eagle Japan program and will spend the summer studying in Japan. We have deliberately encouraged the formation of teams to accomplish specific projects; the NSF-sponsored REU students have served as the nucleus of this group and have provided the continuity and expertise to give opportunities to their peers.

In addition to its research uses, the software the froms the DSPT Workbook is being used in *ME3110, Creative Decisions and Design,* the first course in Mechanical Engineering Design. Both PI's teach sections of this course, about 325 students per year use the software developed by the NSF-REU students. We actively seek continuous quality improvement in our course offerings and the NSF-REU undergraduates have helped to make this a realty. We are laying the foundation to introduce the DSPT Workbook in other courses in the design sequence.

Graduate Students: Jesse Peplinski a doctoral student originally supported on this grant, has received a NSF Graduate Fellowship to work on a related project. His work will add value to the work proposed here. Patrick Koch in both 1993 and 1994 received Honorable Mention in the NSF Graduate Fellowship competition. He has received a Gwaltney Manufacturing Fellowship to pursue his doctoral studies. Arnd Rothe completed his Master's Degree and has returned to Germany to persue doctoral Studies with Professor Beitz.

Education: From the work on aircraft evacuation systems, we have developed both written and oral questions for the Georgia Tech Ph.D. qualifying examination. In addition, the information we obtained about aircraft systems was used for a project for the first graduate-level course in mechanical engineering design in 1993. Three graduate students from our laboratory used the evacuation system problem as a test case as a means to learn about the Pahl and Beitz approach to design. The Aircraft Evacuation System example has been used to introduce the seven TQM Management and Planning tools (in the context of Pahl & Beitz' approach to establishing function structures) to students in our first course in design in Spring 1993: ME3110 - Creative Decisions and Design.

PLEASE NOTE THAT THIS IS IN ADDITION TO THE BENEFITS AND CONTRIBUTIONS DISCUSSED AS A PART OF THE ORIGINAL APPLICATION.

7. **Updated information on animal care and use.** None.

CURRENT SUPPORT

Investigator *Farrokh Mistree*

Support *Current*
Project Title *Design at the Function Level of Abstraction*
Source of Support *National Science Foundation*
Award Amount *$156,069* Period Covered: *12/92-11/95*
Location of Research *Georgia Institute of Technology*
Person-Months of Effort Committed Summer: *0.5 month.*

Support *Current*
Project Title *Design of Hierarchical and Nonhierarchical Systems using Fuzzy Compromise Decision Support Problems*
Source of Support *National Science Foundation*
Award Amount *$213,210* Period Covered: *12/92-11/95*
Location of Research *Georgia Institute of Technology*
Person-Months of Effort Committed Summer: *0.5 month.*

Support *Current*
Project Title *New Approaches to HSCT Multidisciplinary Design and Optimization*
Source of Support *NASA Langley Research Center*
Award Amount *$600,000 (4 Co-PIs + Ind. Partner)* Period Covered: 1/94-12/96
Location of Research *Georgia Institute of Technology*
Person-Months of Effort Committed *Support for one student only.*

Support *Award notice received. Award amount and scope unclear.*
Project Title *Product Realization: An Integrating Theme for Manufacturing Education*
Source of Support *Trchnology Reinvestment Program*
Amount Requested *$2,998,782 (5 Co-PIs)* Period Covered: *3 years*
Location of Research *Georgia Institute of Technology*
Person-Months of Effort Committed *Unclear*

Support *Current*
Project Title *Towards a Multiuser Environment for the Concurrent Design of Open Engineering Systems*
Source of Support *Georgia Tech's Office of the Vice President*
Amount Requested *$19.800 (2 Co-PIs)* Period Covered: *9/93 to 8/94*
Location of Research *Georgia Institute of Technology*
Person-Months of Effort Committed *Support for one student only.*

Support *Current*
Project Title *Development of a Design Learning Simulator*
Source of Support *Georgia Tech's EduTech Institute*
Amount Requested *$12,000 (3 Co-PIs)* Period Covered: *6/94 to 12/94*
Location of Research *Georgia Institute of Technology*
Person-Months of Effort Committed *Support for one student only.*

CURRENT AND PENDING SUPPORT

Appendix vii

Investigator *Janet K. Allen*

Support	*Current*		
Project Title	*Design at the Function Level of Abstraction*		
Source of Support	*National Science Foundation*		
Award Amount	*$156,069*	Period Covered:	*12/92-11/95*
Location of Research	*Georgia Institute of Technology*		
Person-Months of Effort Committed		Calendar:	*2 months.*

Support	*Current*		
Project Title	*Design of Hierarchical and Nonhierarchical Systems using Fuzzy Compromise Decision Support Problems*		
Source of Support	*National Science Foundation*		
Award Amount	*$213,210*	Period Covered:	*12/92-11/95*
Location of Research	*Georgia Institute of Technology*		
Person-Months of Effort Committed		Calendar:	*2 months.*

Support	*Current*		
Project Title	*Development of a Design Learning Simulator*		
Source of Support	*Georgia Tech's EduTech Institute*		
Amount Requested	*$12,000 (3 Co-PIs)*	Period Covered:	*6/94 to 12/94*
Location of Research	*Georgia Institute of Technology*		
Person-Months of Effort Committed		*Support for one student only.*	

E-25-X66
N/A
(New)

APPENDIX D

ANNUAL NSF GRANT PROGRESS REPORT

NSF Program: Design, Manufacturing and Industrial Integration

NSF Award Number: DMI-9396052

PI Name:
Dr. Farrokh Mistree

Period Covered By This Report:
Jan. 1, 1995 -- Dec. 31, 1995

PI Institution:
Georgia Institute of Technology

Date:
April 25, 1996

PI Address:
Woodruff School of Mechanical Engineering
Atlanta, GA 30332-0405

☐ **Check If Continued Funding is Requested**

Please include the following information:

1. Brief summary of progress to date and work to be performed during the succeeding period;
2. Statement of funds estimated to remain unobligated –if more than 20%– at the end of the period for which NSF currently is providing support (not required for participants in the Federal Demonstration Project);
3. Proposed budget for the ensuing year in the NSF format, only if the original award letter did not indicate specific incremental amounts or if adjustments to a planned increment exceeding the greater of 10% or $10,000 are being requested;
4. Current information about other research support of senior personnel, if changed from the previous submission;
5. Any other significant information pertinent to the type of project supported by NSF or as specified by the terms and conditions of the grant;
6. A statement describing any contribution of the project to the area of education and human-resource development, if changed from any previous submission; and
7. Updated information on animal care and use, Institutional Biohazard Committee and Human Subject Certification, if changed substantially from those originally proposed and approved.

S E E A T T A C H E D I N F O R M A T I O N

I certify that to the best of my knowledge (1) the statements herein (excluding scientific hypotheses and scientific opinions) are true and complete, and (2) the text and graphics in this report as well as any accompanying publications or other documents, unless otherwise indicated, are the original work of the signatories or individuals working under their supervision. I understand that the willful provision of false information or concealing a material fact in this report or any other communication submitted to NSF is a criminal offense (U.S. Code, Title 18, Section 1001.)

P.I. Signature:

NSF Form 1328 (1/94)

ANNUAL PROGRESS REPORT FOR THE YEAR JANUARY 1 TO DECEMBER 31, 1995

DESIGN AT THE FUNCTIONAL LEVEL OF ABSTRACTION

NSF GRANT NUMBER DMI-9396052

1. Summary of the work performed and future work:

During project initiation, it is important to be able to represent at a high level of abstraction the functional requirements of the system being designed. We have developed a systems - based approach to modeling functional requirements of the system based on an analogy to Living Systems Theory and associated icons. Components or component assemblies are not evaluated independently, but instead within the context of the functions of the product as a whole. This fosters interaction and assimilation between subsystems from a manufacturing perspective. We make use of a multi-objective selection procedure, so that manufacturing alternatives are evaluated and selected concurrently based not only on manufacturing costs alone, but also life-cycle issues, time to market, environmental concerns and other user-defined measures.

In the earliest stages of conceptual design, the functions a product is to perform are elaborated, but the physical forms of competing concepts are known in only very general terms. It is in these earliest stages that a system being designed can be defined and represented at a high level of abstraction, the function level, to foster the exploration of concepts for meeting the necessary functions. Our work is based on the paradigm of a conceptual model for decision-based concurrent engineering design for the life cycle. Decision-Based Design (DBD) is the starting point for the creation of design methods that are based on the notion that the principal role of an engineer, in the design of an artifact, is to make decisions. DBD can take many forms; our implementation being the Decision Support Problem (DSP) Technique. We focus on identifying the appropriate decisions for Design for Manufacture (DFM) and creating tools to support designers in their decision-making processes. We first develop a product model that captures and handles the uncertain and incomplete product information (see Mistree, et al., 1993; Koch, et al., 1994). This is based on the concepts of Miller's Living Systems Theory, then geometric information is attached to this model. Thus we operate on a model of the product that exists at the *function level of abstraction* and use this representation to introduce manufacturing considerations.

Our solution scheme takes the form of a Heuristic Selection Decision Support Problem, and our computer tool is called FLAME: the **F**unction **L**evel of **A**bstraction **M**anufacturability **E**valuator, Peplinski, 1995. We use this tool to identify, evaluate and select potential manufacturing alternatives for products modeled at the function level of abstraction. We have illustrated some of its uses by exploring the selection of manufacturing processes and materials for a component from a design of an aircraft evacuation system, although our focus is on the method rather than on the results *per se*. Simpson, 1995, has further proposed a method for the introduction of assembly information in the very early stages of design. Rothe, 1994, proposed a method for introducing constraints from other phases of the product's life cycle, especially the disposal phase, to introduce disassembly/reuse criteion and thus identifying environmentally friendly products in the early stages of conceptual design.

This summer we expect to start looking at creating a Living System Analyogy for costing.

REU Supplement: We have had several undergraduates supported on a Research Experiences for Undergraduates (REU) Supplement. This has resulted in further development of *The DSPT Workbook* which is being used by more than 100 students each quarter in *ME 3110: Creative Decisions and Design*. This Workbook includes decision process and planning software, a partitioner for representing the functional requirements of a product using LST icons as well a software for solving selection, coupled selection and compromise Decision Support Problems. Also included are tools for scheduling and planning. Thus, using results the project described above dovetails neatly with NSF Grant DDM 93-96053, that project is described elsewhere in these proceedings.

Publications In Which This Grant Has Been Acknowledged

Journal Articles

1. Mistree, F., Bras, B.A., Smith, W.F. and Allen, J.K., 1995, "Modeling Design Processes: A Conceptual, Decision-Based Approach," *International Journal of Engineering Design and Automation,* in press.
2. Koch, P., Peplinski, J., Allen, J. K. and Mistree, F., "Configuring Systems at the Function Level of Abstraction," *The International Journal of Engineering Design and Automation*, Vol. 1, No. 2, pp. 73-91.
3. P. Koch, J. Peplinski, J.K. Allen, and F. Mistree, 1994, "Designing Using Available Assets: Identifying a Feasible System Configuration", *Behavioral Science,* vol. 30, 229-250.
4. F. Mistree, J.K. Allen and F. Attia, 1993, "Designing at the Function Level of Abstraction", *Behavioral Science,* Vol. 38, 124-138. This paper was invited by the Editor, J.G. Miller and has been substantially edited by him.

Chapter in Book

1. Koch, P.N., Peplinski, J.D., Mistree, F. and Allen, J.K., 1996, "Configuring Systems Using Available Assets: A Conceptual Decision-Based Perspective" in *Mechanical Design Theory and Methodology,* (M. Waldron, Ed.), New York, Springer-Verlag, Chapter 7, pp. 127-160.

Conferences

1. Peplinski, J.D., Allen, J.K. and Mistree, F., "Integrating Product Design with Manufacturing Process Design Using the Robust Concept Expolration Method," *AMSE Design Theory and Methodology COnference,* Paper DETC/DTM, 1052.
2 Koch, P.N., Barlow, A., Allen, J.K. and Mistree, F., 1996, "Configuring Turbine Propulsion Systems Using Robust Concept Exploration," *ASME Design Automation Conference,* Paper 1285.
3. Peplinski, J.P., Koch, P.N., Allen, J.K. and Mistree, F., "FLAME: Function Level of Abstraction Manufacturing Evaluator," *ASME Design for Manufacturing Symposium,* Boston, MA, September 1995.
4. Simpson, T.W., Bauer, M.D., Allen, J.K. and Mistree, F., "Implementation of DFA in Conceptual and Embodiment Design using Decision Support Problems," *ASME Design Automation Conference,* Boston, MA, September 1995.
5. Mistree, F. and Allen, J.K., 1995, "Designing for Function and Manufacturability at a High Level of Abstraction," *Proceedings, NSF Design and Manufacturing Grantees Conference,* San Diego, CA, January 4-6, 1995, 1-2.
6. F. Mistree and J.K. Allen, 1994, "Designing at the Function Level of Abstraction", *Proceedings NSF Grantees Conference on Design and Manufacturing Systems Research,* Cambridge, MA, January 1994, 71-72.
7. F. Mistree, J.K. Allen and F. Attia, "Designing at the Function Level of Abstraction", *Proceedings NSF Grantees Conference on Design and Manufacturing Systems Research, Charlotte,* NC, January 1993.

8. Chen, W., Allen, J.K. and Mistree, F., "Hierarchical Selection in Gas Turbine Maintenance Management," *Advances in Design Automation,* (Gilmore, B. J., Hoeltzel, D., Azarm, S. and Eschenauer, H., Eds.), NY, ASME, 1993. 87-96, ASME DE-Vol. 65-1.

Theses

1. T. Simpson, *Development of a Design Process for Realizing Open Engineering Systems;* M.S. Thesis, Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA, expected,1995.
2. J.D. Peplinski, *Design for Manufacture at the Function Level of Abstraction,* M.S. Thesis, Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA, November 1994.
3. P.N. Koch, *Design Using Available Assets at the Functional Level of Abstraction,* M.S. Thesis, Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA, June 1994.
4. A. Rothe, *Decision Support Problems in the Pahl/Beitz Design Process,* M.S. Thesis, Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA, March 1994.

The first three students are currently studying for their doctorates at Georgia Tech, A. Rothe is studying for his Ph.D. at the Technical Univeristy of Berlin.

2. Not required.

3. Not required.

4. See attached current and pending research support forms for Farrokh Mistree and Janet K. Allen.

5. Not required.

6. No change.

7. Not required.

CURRENT AND PENDING SUPPORT

Investigator	***Farrokh Mistree, PI***	
Support	*Pending*	
Project Title	Modeling the Interactions of Multidisciplinary Design: A Game Theoretic Approach	
Source of Support	*National Science Foundation*	
Amount Requested	$353,520	Period Covered: *9/96-8/99*
Location of Research	*Georgia Institute of Technology*	
Person-Months of Effort Committed		Summer: *0.5 month.*

Support	*Pending*	
Project Title	Enterprise Design: Integrating Product, Process and Organization	
Source of Support	*National Science Foundation*	
Amount Requested	$317,547	Period Covered: *9/96-8/99*
Location of Research	*Georgia Institute of Technology*	
Person-Months of Effort Committed		Summer: *0.5 month.*

Support	*Pending*	
Project Title	A Robust Concept Exploration Method For Configuring Power and Propulsion Systems	
Source of Support	*National Science Foundation*	
Amount Requested	$317,355	Period Covered: *9/96-8/99*
Location of Research	*Georgia Institute of Technology*	
Person-Months of Effort Committed		Summer: *0.5 month.*

Support	*Current / Terminating*	
Project Title	*Design at the Function Level of Abstraction*	
Source of Support	*National Science Foundation*	
Award Amount	*$156,069*	Period Covered: *12/92-11/96*
Location of Research	*Georgia Institute of Technology*	
Person-Months of Effort Committed		Summer: *0.5 month.*

Support	*Current / Terminating*	
Project Title	*Design of Hierarchical and Nonhierarchical Systems using Fuzzy Compromise Decision Support Problems*	
Source of Support	*National Science Foundation*	
Award Amount	*$213,210*	Period Covered: *12/92-6/96*
Location of Research	*Georgia Institute of Technology*	
Person-Months of Effort Committed		Summer: *0.5 month.*

Support	*Current*	
Project Title	*New Approaches to HSCT Multidisciplinary Design and Optimization*	
Source of Support	*NASA Langley Research Center*	
Award Amount	*$600,000 (4 Co-PIs + Ind. Partner)*	Period Covered: 1/94-12/96
Location of Research	*Georgia Institute of Technology*	
Person-Months of Effort Committed		*Support for one student only.*

CURRENT AND PENDING SUPPORT

Investigator	***Farrokh Mistree, PI***

Support	*Current*		
Project Title	*NASA Graduate Student Fellowship*		
Source of Support	*NASA Langley Research Center*		
Award Amount	*$63,000*	Period Covered:	*6/93 to 10//96*
Location of Research	*Georgia Institute of Technology*		
Person-Months of Effort Committed		*Support for one doctoral student*	

Project Title	*Product Realization: An Integrating Theme for Manufacturing Education*		
Source of Support	*Technology Reinvestment Program*		
Award Amount	*$1,000,000 (5 Co-PIs)*	Period Covered:	*10/94-9/97*
Location of Research	*Georgia Institute of Technology*		
Person-Months of Effort Committed		Summer:	*1 month.* *No student*

Support	*Current*		
Project Title	*Virtual Design, Service and Demanufacture Studio*		
Source of Support	*NSF Rapid Prototyping Initiative*		
Award Amount	*$400,000 (3 Co-PIs)*	Period Covered:	*10/94-9/97*
Location of Research	*Georgia Institute of Technology*		
Person-Months of Effort Committed		Summer:	*0.5 month.* *No student.*

Support	*Current / Pending*
Project Title	*Product Realization using the Decision Support Problem Technique*
Sources of Support	Current: *Kvaerner Inc., Norway; Allison Engine Company.*
Award	2 doctoral students from Kvaerner (transportation system). 1 doctoral student (18 months) from Allison Engine Company.

CURRENT AND PENDING SUPPORT

Investigator ***Janet K. Allen, Co-PI***

Support	*Pending*		
Project Title	Modeling the Interactions of Multidisciplinary Design: A Game Theoretic Approach		
Source of Support	*National Science Foundation*		
Amount Requested	$353,520	Period Covered:	*9/96-8/99*
Location of Research	*Georgia Institute of Technology*		
Person-Months of Effort Committed		Calendar:	*2month.*

Support	*Pending*		
Project Title	Enterprise Design: Integrating Product, Process and Organization		
Source of Support	*National Science Foundation*		
Amount Requested	$317,547	Period Covered:	*9/96-8/99*
Location of Research	*Georgia Institute of Technology*		
Person-Months of Effort Committed		Calendar:	*2 month.*

Support	*Pending*		
Project Title	A Robust Concept Exploration Method For Configuring Power and Propulsion Systems		
Source of Support	*National Science Foundation*		
Amount Requested	$317,355	Period Covered:	*9/96-8/99*
Location of Research	*Georgia Institute of Technology*		
Person-Months of Effort Committed		Calendar:	*2 month.*

Support	*Current / Terminating - co-Principal Investigator*		
Project Title	*Design at the Function Level of Abstraction*		
Source of Support	*National Science Foundation*		
Award Amount	*$156,069*	Period Covered:	*12/92-11/96*
Location of Research	*Georgia Institute of Technology*		
Person-Months of Effort Committed		Academic:	*1month.*

Support	*Current / Terminating - co-Principal Investigator*		
Project Title	*Design of Hierarchical and Nonhierarchical Systems using Fuzzy Compromise Decision Support Problems*		
Source of Support	*National Science Foundation*		
Award Amount	*$213,210*	Period Covered:	*12/92-6/96*
Location of Research	*Georgia Institute of Technology*		
Person-Months of Effort Committed		Academic:	*1month.*

E-25-X66 #1

OMB Number 345-0058

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Permit No. G-69

PI/PD Name and Address

Farrokh Mistree
Dept. of Mechanical Engineering
Georgia Institute of Tech
Woodruff School of Mechanical Eng.
Atlanta GA 30332-0405

NATIONAL SCIENCE FOUNDATION
FINAL PROJECT REPORT

PART I - PROJECT IDENTIFICATION INFORMATION

1. Program Official/Org. George A. Hazelrigg - DMI

2. Program Name DESIGN AND INTEGRATION ENGINEERING PROGR

3. Award Dates (MM/YY) From: 12/92 To: 08/96

4. Institution and Address
GA Tech Res Corp - G11
Administration Building
Atlanta GA 30332

5. Award Number 9396052

6. Project Title
Designing at the Functional Level of Abstraction

** You are encouraged to submit your Final Project Report electronically **
** through the NSF FastLane home page (www.fastlane.nsf.gov). **

This Packet Contains
NSF Form 98A
And 1 Return Envelope

t Conditions (Article 17, GC-1, and Article 9, FDP-11) require submission of a Final Project (NSF Form 98A) to the NSF program officer no later than 90 days alter the expiration of the .. Final Project Reports for expired awards must be received before new awards can be made · Grants Policy Manual Section 677).

ow, or on a separate page attached to this form, provide a summary of the completed projects and technical information. Be e to include your name and award number on each separate page. See below for more instructions.

PART II - SUMMARY OF COMPLETED PROJECT (for public use)

e summary (about 200 words) must be self-contained and intelligible to a scientifically literate reader. Without restating the ject title, it should begin with a topic sentence stating the project's major thesis. The summary should include, if pertinent he project being described, the following items:

he primary objectives and scope of the project
he techniques or approaches used only to the degree necessary for comprehension
he findings and implications stated as concisely and informatively as possible

SEE ATTACHED SHEET

PART III - TECHNICAL INFORMATION (for program management use)

t references to publications resulting from this award and briefly describe primary data, samples, physical collections, entions, software, etc. created or gathered in the course of the research and, if appropriate, how they are being made available he research community. Provide the NSF Invention Disclosure number for any invention.

rtify to the best of my knowledge (1) the statements herein (excluding scientific hypotheses and scientific opinion) are true and complete, and the text and graphics in this report as well as any accompanying publications or other documents, unless otherwise indicated, are the original k of the signatories or of individuals working under their supervision. I understand that willfully making a false statement or concealing a erial fact in this report or any other communication submitted to NSF is a criminal offense (U.S. Code, Title 18, Section 1001).

	8/30/96
Principal Investigator/Project Director Signature	**Date**

IMPORTANT - MAILING INSTRUCTIONS

Return this *entire* packet plus all attachments in the envelope attached to the back of this form. Please copy the information from Part I, Block 1 to the *Attention* block on the envelope.

(To be submitted to cognizant Program Officer upon completion of project)

The data requested below are important for the development of a statistical profile on the personnel supported by Federal grants. The information on this part is solicited in resonse to Public Law 99-383 and 42 USC 1885C. All information provided will be treated as confidential and will be safeguarded in accordance with the provisions of the Privacy Act of 1974. You should submit a single copy of this part with each final project report. However, submission of the requested information is not mandatory and is not a precondition of future award(s). Check the "Decline to Provide Information" box below if you do not wish to provide the nformation.

Please enter the numbers of individuals supported under this grant.
Do not enter information for individuals working less than 40 hours in any calendar year.

	Senior Staff		Post-Doctorals		Graduate Students		Under-Graduates		Other Participants[1]	
	Male	Fem.	Male	Fem.	Male	Fem.	Male	Fem.	Male	Fem.
A. Total, U.S. Citizens		1			3					
B. Total, Permanent Residents	1									
U.S. Citizens or Permanent Residents[2]:										
American Indian or Alaskan Native										
Asian.....	1									
Black, Not of Hispanic Origin.....										
Hispanic										
Pacific Islander										
White, Not of Hispanic Origin		1								
C. Total, Other Non-U.S. Citizens					1					
Specify Country 1. GERMANY					1					
2.										
3.										
D. Total, All participants (A + B + C)										
Disabled[3]					4					

☐ Decline to Provide Information: Check box if you do not wish to provide this information (you are still required to return this page along with Parts I-III).

[1] Category includes, for example, college and precollege teachers, conference and workshop participants.

[2] Use the category that best describes the ethnic/racial status fo all U.S. Citizens and Non-citizens with Permanent Residency. *(If more than one category applies, use the one category that most closely reflects the person's recognition in the community.)*

[3] A person having a physical or mental impairment that substantially limits one or more major life activities; who has a record of such impairment; or who is regarded as having such impairment. *(Disabled individuals also should be counted under the appropriate ethnic/racial group unless they are classified as "Other Non-U.S. Citizens.")*

AMERICAN INDIAN OR ALASKAN NATIVE: A person having origins in any of the original peoples of North America and who maintains cultural identification through tribal affiliation or community recognition.

ASIAN: A person having origins in any of the original peoples of East Asia, Southeast Asia or the Indian subcontinent. This area includes, for example, China, India, Indonesia, Japan, Korea and Vietnam.

BLACK, NOT OF HISPANIC ORIGIN: A person having origins in any of the black racial groups of Africa.

HISPANIC: A person of Mexican, Puerto Rican, Cuban, Central or South American or other Spanish culture or origin, regardless of race.

PACIFIC ISLANDER: A person having origins in any of the original peoples of Hawaii; the U.S. Pacific territories of Guam, American Samoa, and the Northern Marinas; the U.S. Trust Territory of Palau; the islands of Micronesia and Melanesia; or the Philippines.

WHITE, NOT OF HISPANIC ORIGIN: A person having origins in any of the original peoples of Europe, North Africa, or the Middle East.

FINAL REPORT FOR GRANT 9396052
DESIGN AT THE FUNCTIONAL LEVEL OF ABSTRACTION

DESIGN AND INTEGRATION ENGINEERING PROGRAM
G.A. HAZELRIGG, PROGRAM OFFICIAL

PART II - SUMMARY OF COMPLETED PROJECT

How can one include manufacturing considerations when only the functions of a product are known?

This question is address in the context of Decision-Based Design (DBD). DBD is the starting point for the creation of design methods that are based on the notion that the principal role of an engineer, in the design of an artifact, is to make decisions. Our embodiment of DBD is called the *Decision Support Problem Technique.* We first develop a product model that captures and handles the uncertain and incomplete product information. A *living system analogy* (model) of the artifact is created; it is based on Miller's *Living Systems Theory.* Then geometric information is attached to this model, Koch, 1994. Thus we operate on a model of the product that exists at the *function level of abstraction* and use this representation to introduce manufacturing considerations. Our solution scheme takes the form of a Heuristic Selection Decision Support Problem, and our computer tool is called FLAME: the Function Level of Abstraction Manufacturability Evaluator, Peplinski, 1995. We use this tool to identify, evaluate and select potential manufacturing alternatives for products modeled at the function level of abstraction. Simpson, 1995, has further proposed a method for the introduction of assembly information in the very early stages of design. Rothe, 1994, proposed a method for introducing constraints from other phases of the product's life cycle, especially the disposal phase, to introduce disassembly/reuse criterion and thus identifying environmentally friendly products in the early stages of conceptual design.

The NSF REU supplements for this grant have been used to support undergraduate students who have developed a Design Learning Simulator that facilitates design based on the outcome of our research. This material is being used in one undergraduate course, ME3110. The material may be viewed at: http://www.srl.gatech.edu/DLS/.

PART III - TECHNICAL INFORMATION
PUBLICATIONS IN WHICH THIS GRANT HAS BEEN ACKNOWLEDGED

Publications in Which This Grant Has Been Acknowledged
Journal Articles

1. Peplinski, J., Koch, P.N., Allen, J.K. and Mistree, F., "Design Using Available Assets: A Paradigm Shift in Design for Manufacture," *Concurrent Engineering: Research and Applications,* (in press).
2. Mistree, F., Bras, B.A., Smith, W.F. and Allen, J.K., 1995, "Modeling Design Processes: A Conceptual, Decision-Based Approach," *International Journal of Engineering Design and Automation,* Vol. 1, No. 4, 209-221.
3. Koch, P., Peplinski, J., Allen, J. K. and Mistree, F., "Configuring Systems at the Function Level of Abstraction," *The International Journal of Engineering Design and Automation,* Vol. 1, No. 2, pp. 73-91.
4. Koch, P.N., Peplinski, J., Allen, J.K. and Mistree, F., 1994, "Designing Using Available Assets: Identifying a Feasible System Configuration", *Behavioral Science,* vol. 30, 229-250.